EVAPORATIVE TECHNOLOGIES FOR ENERGY EFFICIENT HIGH PERFORMANCE BUILDINGS

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- Presented To:

Energy Efficiency In Government Buildings Retrofits Workshop

Orlando, FL

February 4-6, 2005

What Is A “High Performance” Building?

- Combines energy efficiency and indoor environmental quality
- Energy efficiency
  - Minimizes use of virgin/raw energy sources
- Indoor environmental quality (IEQ)
  - Optimizes indoor air quality (IAQ)
  - Provides stable thermal comfort
  - Optimizes lighting (including daylighting) and noise
- New construction offers greater opportunities, but retrofits of existing buildings can be easily achieved to provide significant benefits for both the owner/operator and the occupants

Is There A Conflict Between Energy Efficiency And Indoor Air Quality?

- ASHRAE Standard 62.1 (Ventilation For Acceptable Indoor Air Quality)
  - The more outdoor air (i.e. increased ventilation), the better the IAQ
- ASHRAE Standard 90.1(Energy Standard For Buildings)
- Both are “minimum” standards…they are starting points not end points
  - The USGBC’s ***LEED™*** program uses Standard 90.1 as its base line…no points unless you go beyond the base line!

So…Is There A Conflict?

- High performance hybrid HVAC equipment and designs can eliminate the outdoor air penalty and thus eliminate any potential conflict between energy efficiency and indoor air quality.

IAQ
Why Is It More Important Than Ever?

- Findings from many studies indicate that:
  - Poor IAQ is linked to health problems
  - Inadequate ventilation is a major cause
  - Mold, germs and contaminants spread by mechanical recirculation systems are a major cause
  - Poor humidity control is a contributing factor
  - Poor building pressurization is a contributing factor
  - Absenteeism costs
  - Worker turnover costs
  - Lost productivity

High Performance HVAC Benefits

- Innovative engineering and design can:
  - Improve system performance
  - Reduce first costs
  - Reduce life cycle costs
  - Increase building/equipment life
  - Improve IAQ and IEQ

High Performance Hybrid HVAC: Some Design Strategies

- **Dual Path Ventilation –** Separation of ventilation from heating and cooling processes permits elimination of terminal reheat and effective management of ventilation.
- **Energy Recovery** - Recycling cooling/heating energy permits ventilation air to be introduced at low cost. Harvest the energy already at hand before using new energy resources.
- **Evaporative Cooling and Humidification** - These are the only processes which can close the loop on latent energy. They permit the avoidance of most cooling and humidification energy, **and are applicable in all climactic environments**.
- **Displacement Ventilation** - Permits smaller, 100% outside air systems to replace much larger systems, greatly reduces energy use, and increases ventilation effectiveness.

High Performance Hybrid HVAC: Some Design Strategies

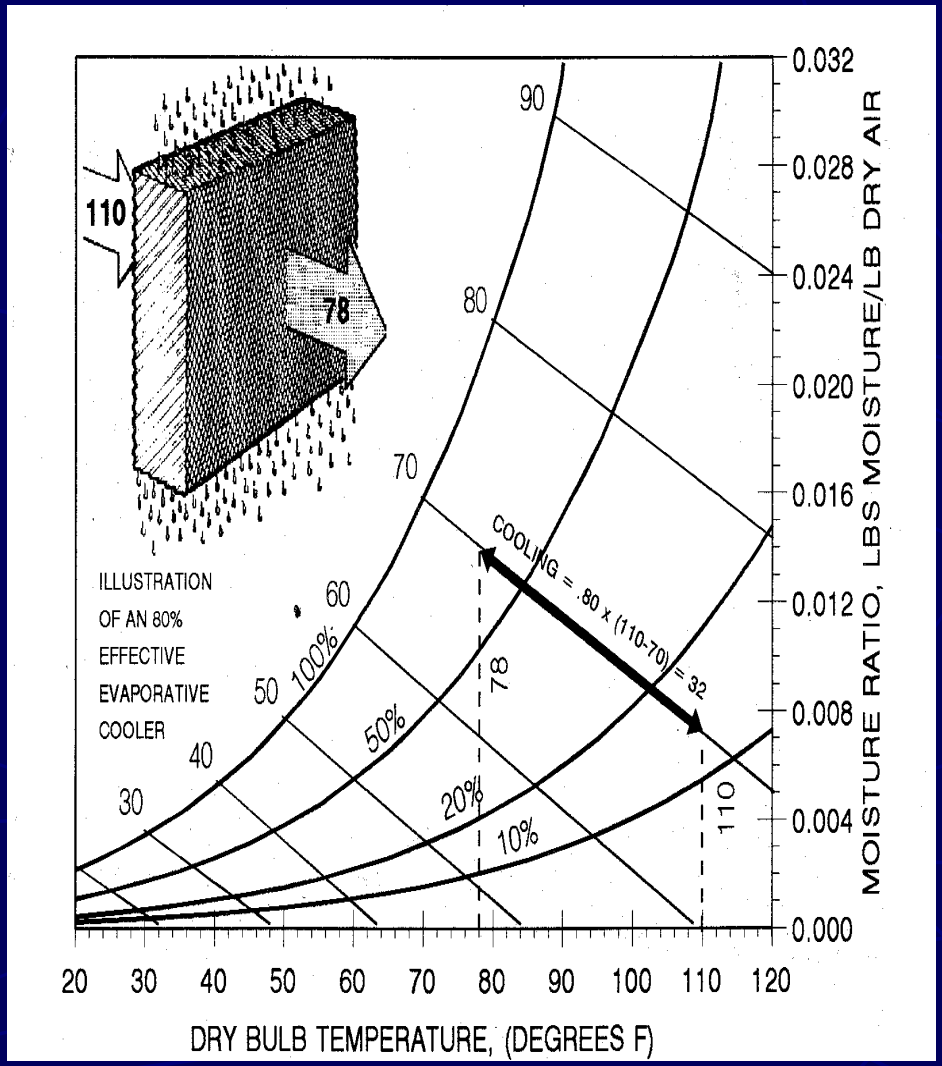
- **Thermal Storage** - Properly employed, thermal storage can sharply reduce both the quantity and cost of cooling energy use.
- **Process Synergism** - Synergy between two or more components will achieve more out of them than either process could provide alone.
- **Multi-Functional Use** - Individual components can be used to serve multiple design objectives. This reduces parasitic losses.
- **Ampflification** - Multiple heat exchangers can be used to amplify both cooling and heating energy for recovery while also eliminating the need for terminal reheat

Evaporative Cooling
A Very Powerful Tool

- Evaporative cooling technologies form the backbone of energy efficient high performance hybrid HVAC systems
- There are **2** forms of evaporative cooling
  - **Direct**
    - Draws warm air through a wetted media
  - **Indirect**
    - Utilizes a plate and frame air-to-air heat exchanger to separate the supply air from the water used for evaporation
    - Uses a secondary air stream to reject heat from the evaporation process

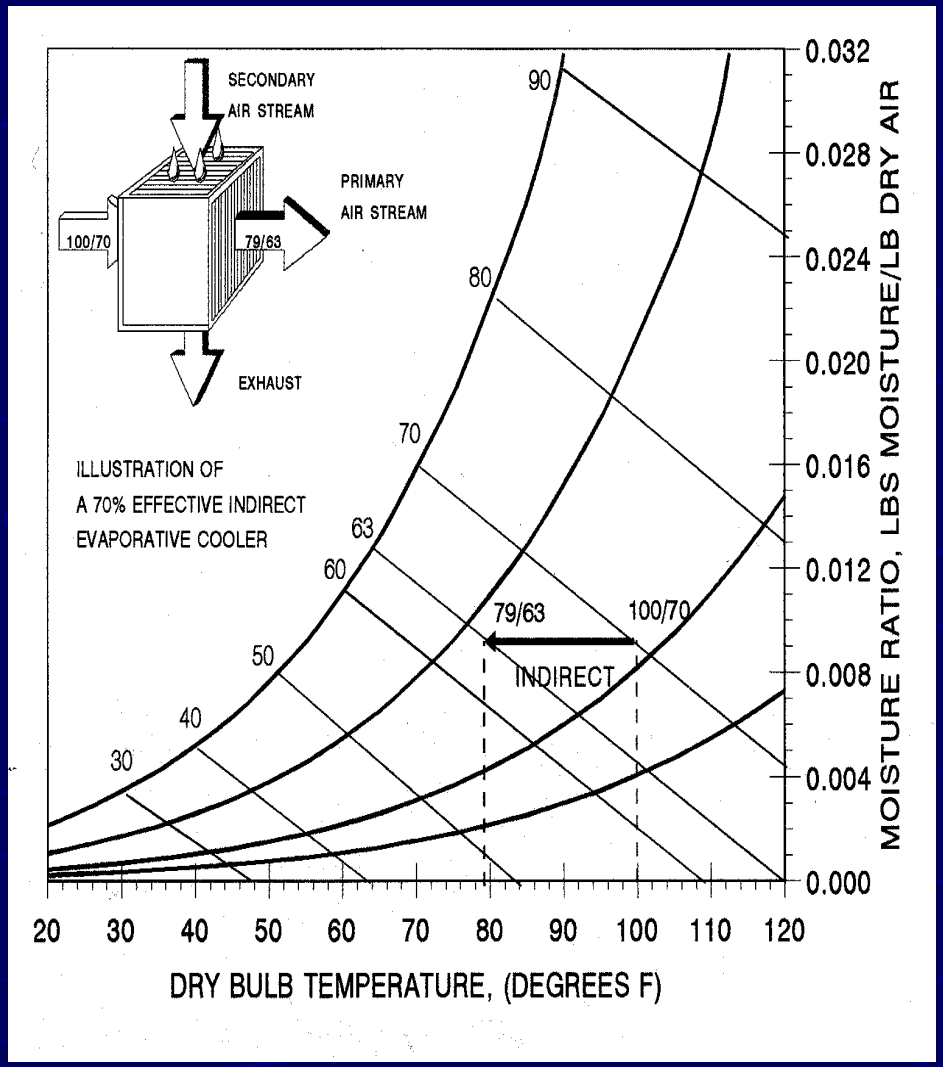
Direct Evaporative Cooling Cycle

- **Effectiveness** is defined by the following equation:
- $E = (TI_{db} - TD_{db}) \div (TI_{db} - TI_{wb})$
- **Discharge Temperature** can be determined by the following equation:
- $TD_{db} = TI_{db} - [E \times (TI_{db} - TI_{wb})]$
- Factors affecting effectiveness are:
  - Type of Media
  - Depth of Media
  - Face Velocity



Indirect Evaporative Cooling Cycle

- **Effectiveness** is defined by the following equation:
- $E = (TI_{db} - TD_{db}) \div (TI_{db} - TIS_{wb})$
- **Discharge Temperature** can be determined by the following equation:
- $TD_{db} = TI_{db} - [E \times (TI_{db} - TIS_{wb})]$
- Factors affecting effectiveness are:
  - Type of heat exchanger
  - Supply air flow through the heat exchanger
  - Secondary air flow
  - Use of outside air vs. building exhaust as the secondary air source



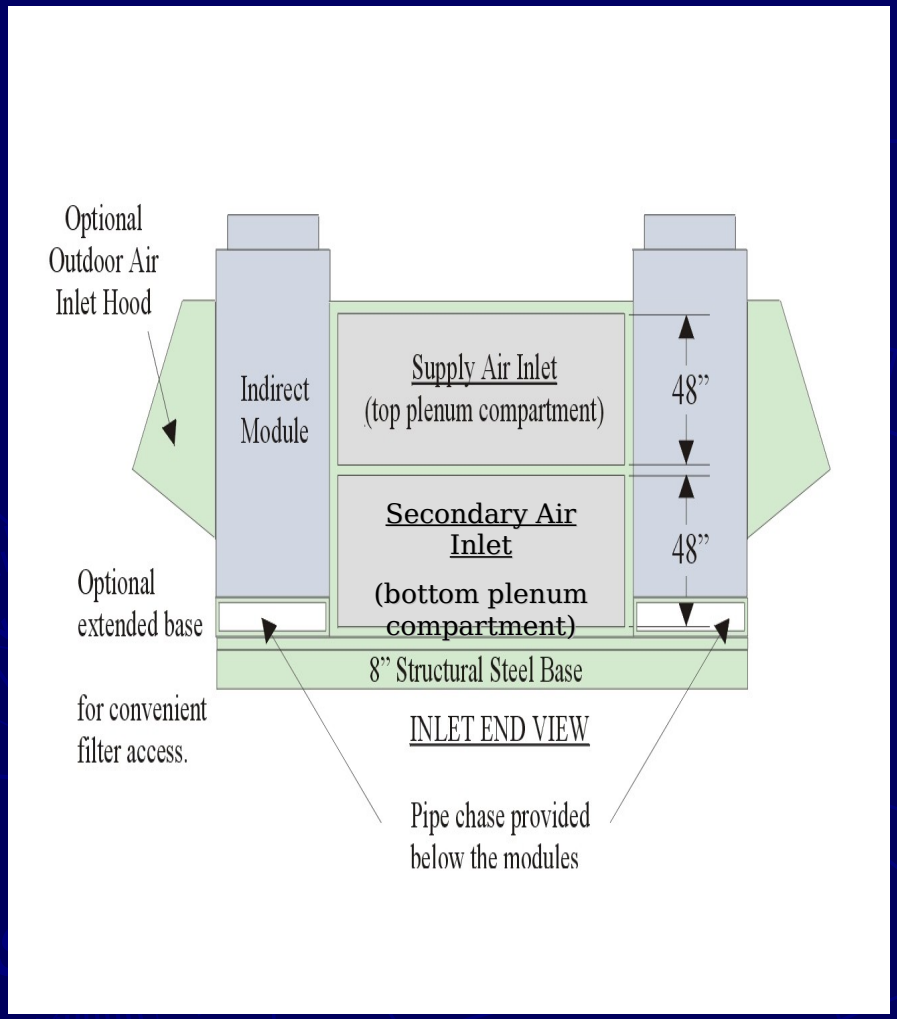
Advantages of Indirect Cooling/Heating

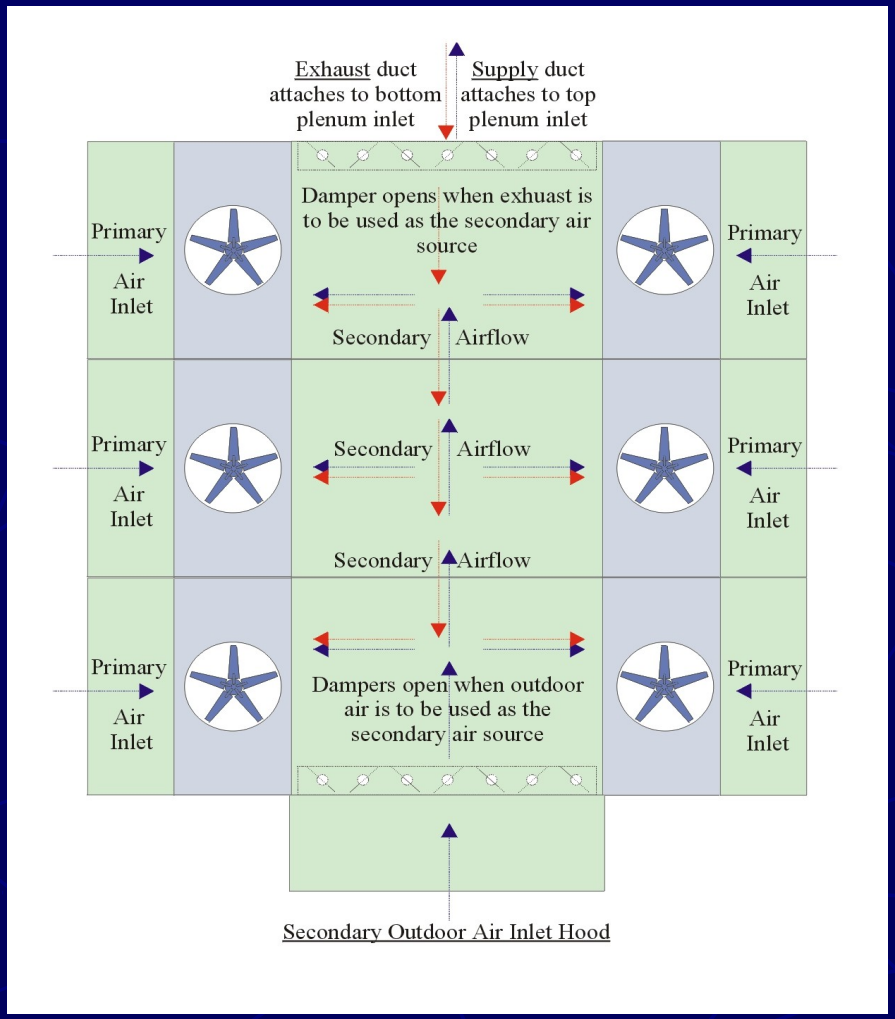
- Provides a sensible cooling process
- Extends the effective Economizer range
- Meets base cooling loads under part load conditions most of the time
- Can be used to provide winter energy (heat) recovery
- Makes 100% outside air applications more economical than recirculation systems
- Reduces the need for refrigeration (by ~50%)
- Reduces the need for mechanical heating (by 30-70%)
- No cross-contamination

An Indirect Evaporative Module

1,000 CFM to 15,000 CFM

Indirect Evaporative Multi-Module Units



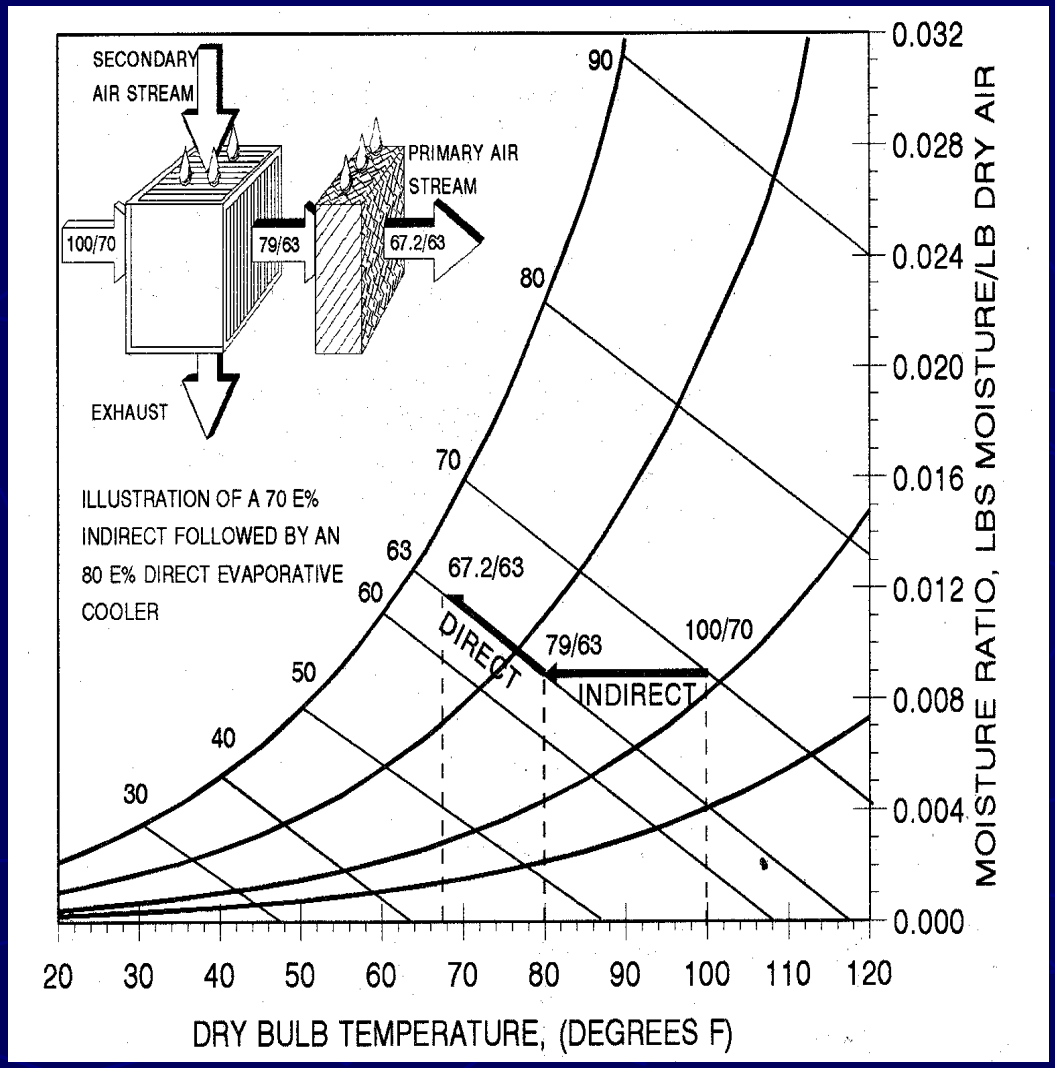


Up to 90,000 CFM

Indirect Evaporative Multi-Module Unit

Indirect/Direct Evaporative Cooling Cycle

* An Indirect/Direct combination will provide cooler air than either process by itself
* In certain climates this combined process alone will provide true “comfort cooling”
* In **all** climates this will provide “relief cooling”



Performance Chart (Low Wet Bulb Area)

SACRAMENTO, CALIFORNIA

Performance of Evaporative Cooling and Heat Recovery Technologies

Ambient OSA DB/WB	Hours/ Year	DIRECT	INDIRECT OSA as Secondary Air	INDIRECT Bldg. Exhaust as Secondary Air	INDIRECT /DIRECT OSA as Secondary Air
107/70 (34.1)	7	74/70	79/61 (27.2)	74/59 (25.9)	63/61
102/70 (43.1)	59	73/70	78/63 (28.7)	73/61 (27.2)	65/63
97/68 (32.5)	144	71/68	75/61 (27.2)	72/60 (26.5)	62/61
92/66 (30.9)	242	69/66	72/60 (26.5)	70/59 (25.9)	61/60
87/65 (30.1)	301	67/65	70/59 (25.9)	69/59 (25.9)	60/59
82/63 (27.3)	397	65/63	68/58 (25.2)	68/58 (25.2)	59/58
77/61 (27.2)	497	63/61	65/57 (24.7)		58/57
72/59 (25.9)	641	60/59	62/55 (23.4)		56/55
67/57 (24.7)	821	58/57	60/54 (22.7)		55/54
62/54 (22.7)	1086	55/54	56/52 (21.5)		53/52

The above discharge temperatures (°F) are based on the following:

1. 75% Indirect Evaporative Effectiveness
2. 90% Direct Evaporative Effectiveness
3. 60% Heat Recovery Effectiveness
4. 75°F Building Exhaust Dry Bulb Temperature (Heat Recovery)
5. 63°F Building Exhaust Wet Bulb Temperature (Cooling)
6. DB = Dry Bulb Temperature
7. WB = Wet Bulb Temperature
8. OSA = Outside Air
9. ( ) Indicates Enthalpy Of Air

Performance Chart (High Wet Bulb Area)

CHICAGO, ILLINOIS

Performance of Evaporative Cooling and Heat Recovery Technologies

Ambient OSA DB/WB	Hours/ Year	DIRECT	INDIRECT OSA as Secondary Air	INDIRECT Bldg. Exhaust as Secondary Air	INDIRECT /DIRECT OSA as Secondary Air	HEAT RECOVERY
97/76 (39.5)	6	78/76	81/71 (35.0)	71/69 (33.3)	72/71	
92/74 (37.7)	58	76/74	78/70 (34.1)	70/68 (32.5)	71/70	
87/72 (35.9)	165	73/72	76/69 (33.3)	69/67 (31.7)	70/69	
82/70 (34.1)	324	71/70	73/67 (31.7)	68/66 (30.9)	68/67	
77/67 (31.7)	487	68/67	70/65 (30.1)	67/64 (29.4)	66/65	
72/64 (29.5)	681	65/64	66/62 (27.9)	65/6227.9)	63/62	
67/61 (27.2)	759	62/61	63/59 (25.9)	64/60 (26.5)	60/59	
62/57 (24/7)	700	58/57	60/56 (24.0)		57/56	
57/52 (21.5)	604	53/52	53/50 (`20.3)		51/50	
52/47 (18.8)	581	48/47	48/45 17.7)		46/45	66
47/43	565					64
42/38	472					62
37/34	725					60
32/30	869					58
27/25	589					56
22/21	371					54
17/16	231					52
12/11	164					50
7/6	115					48
2/1	89					46
-3	53					44
-8	27					42
-13	11					40
-17	2					38

Performance Chart (Very High Wet Bulb Area)

BATON ROUGE, LOUISIANA

Performance of Evaporative Cooling and Heat Recovery Technologies

Ambient OSA DB/WB	Hours/ Year	DIRECT	INDIRECT OSA as Secondary Air	INDIRECT Bldg. Exhaust as Secondary Air	INDIRECT /DIRECT OSA as Secondary Air	HEAT RECOVERY
97/78 (41.7)	13	80/78	83/74 (37.7)	72/71 (35.0)	75/74	
92/76 (39.5)	211	78/76	80/73 (36.8)	70/69 (33.3)	74/73	
87/75 (38.6)	464	76/75	78/72 (35.9)	69/69 (33.3)	73/72	
82/72 (35.9)	984	73/72	75/70 (34.1)	68/68 (32.5)	71/70	
77/70 (34.1)	1214	71/70	72/68 (32.5)	67/67 (31.7)	69/68	
72/67 (31.7)	1517	68/67	68/66 (30.9)	65/65 (30.1)	66/65	
67/62 (27.9)	916	63/62	63/61 (27.3)		62/61	
62/58 (25.2)	678	59/58	59/57 (24.7)		58/57	
57/52 (21.5)	677	53/52	53/50 (20.3)		51/50	
52/47 (18.8)	601	48/47	48/45 (17.7)		46/45	66
47/43	543					64
42/39	296					62
37/34	249					60
32/30	171					58
27/25	22					56
22/23	4					54

Performance Chart (Low Wet Bulb Area)

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Performance of Evaporative Cooling and Heat Recovery Technologies

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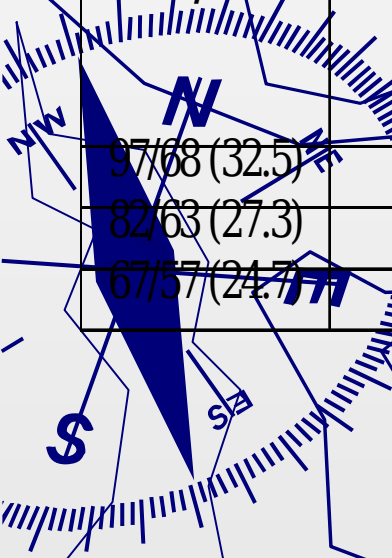

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67/62 (27.9)	916	63/62	63/61 (27.3)		62/61	
57/52 (21.5)	677	53/52	53/50 (20.3)		51/50	
27/25	22					56

Industrial Spaces

- IAQ is as much a concern in industrial spaces as it is in institutional/office spaces… perhaps more!
- So, what is the usual solution
  - Use make-up air units to increase ventilation and make up for process exhaust (most of these units do not cool the outside air)
  - Open up the doors and windows
  - Bring out the floor fans
- This may assist IAQ, but does little to control heat stress

Heat Stress…Affects And Solutions

NASA Report CR-1205-1 (Heat Stress)

Effective Temperature	75	80	85	90	95	100	105
Loss in Work Output	3%	8%	18%	29%	45%	62%	79%
Loss in Accuracy	-	5%	40%	300%	700%	-	-

- ACGIH has established guidelines for reducing heat stress, including:
  - Increased rates of ventilation
  - **Evaporative cooling of ventilation air**
  - Displacement ventilation with stratification
  - Increased fluid intake

Existing Chilled Water Systems

- Often an industrial building will have a chilled water system in place to provide relief cooling
- Just as often, the load inside the facility increases to the point where the chiller no longer can maintain desired space conditions
- The solution…use an indirect evaporative module to pre-cool (and pre-heat) the outdoor air to reduce the outdoor air load on the chiller (or boiler)

Industrial Chilled Water/Make-up Air Retrofit

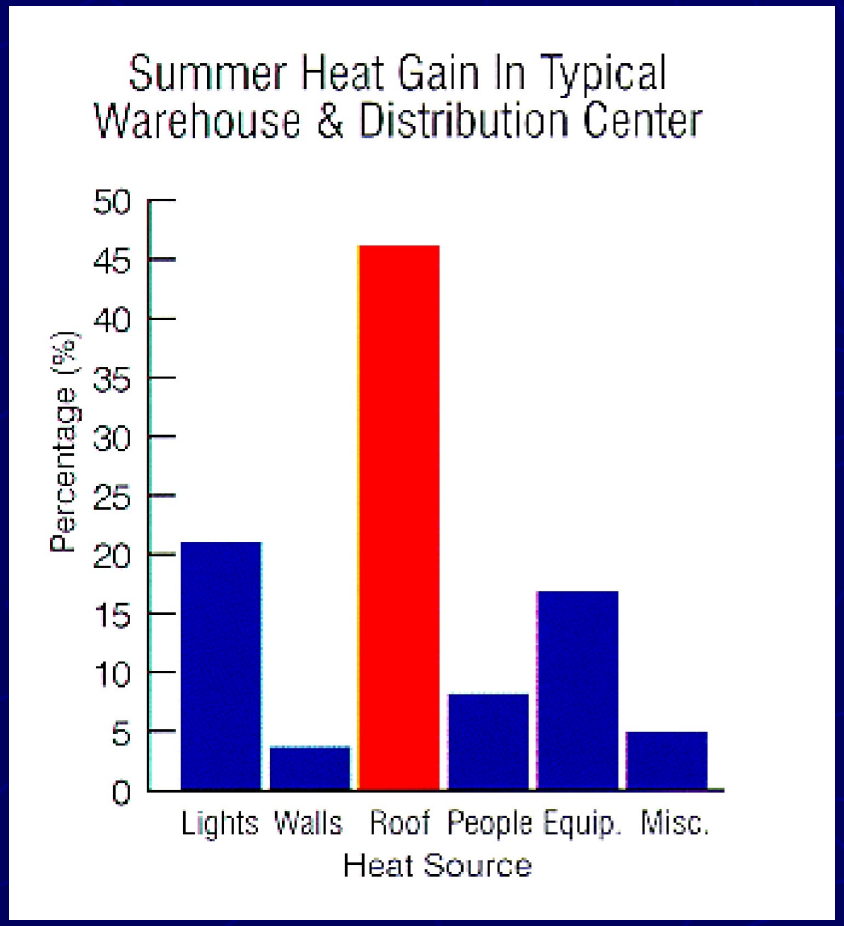
Before: 18,000 CFM Outside Air Hood

After: 18,000 CFM Indirect Evaporative Pre-Cooler

Benefit: Eliminated The Need To Double The Size Of The Existing Chilled Water Plant

Industrial Cooling: Roof Misting

- Roof load heat gains are substantial in most industrial facilities
- Internal heat gains rise dramatically
- **Roof Misting** can drop the roof temperature up to 50°F
- Every 1.5 gallons of water that is evaporated absorbs more than 12,000 BTUs (a **ton** of cooling)



Industrial Cooling: Roof Misting

- **Roof Misting** can virtually eliminate the roof load
- Non-air conditioned buildings can lower space conditions **8°F to 12°F**
- Air conditioned buildings will reduce the load on the roof-top units and increase their performance
- Can extend the roof life by up to 50%

Industrial Cooling: Turbine Cooling Boost

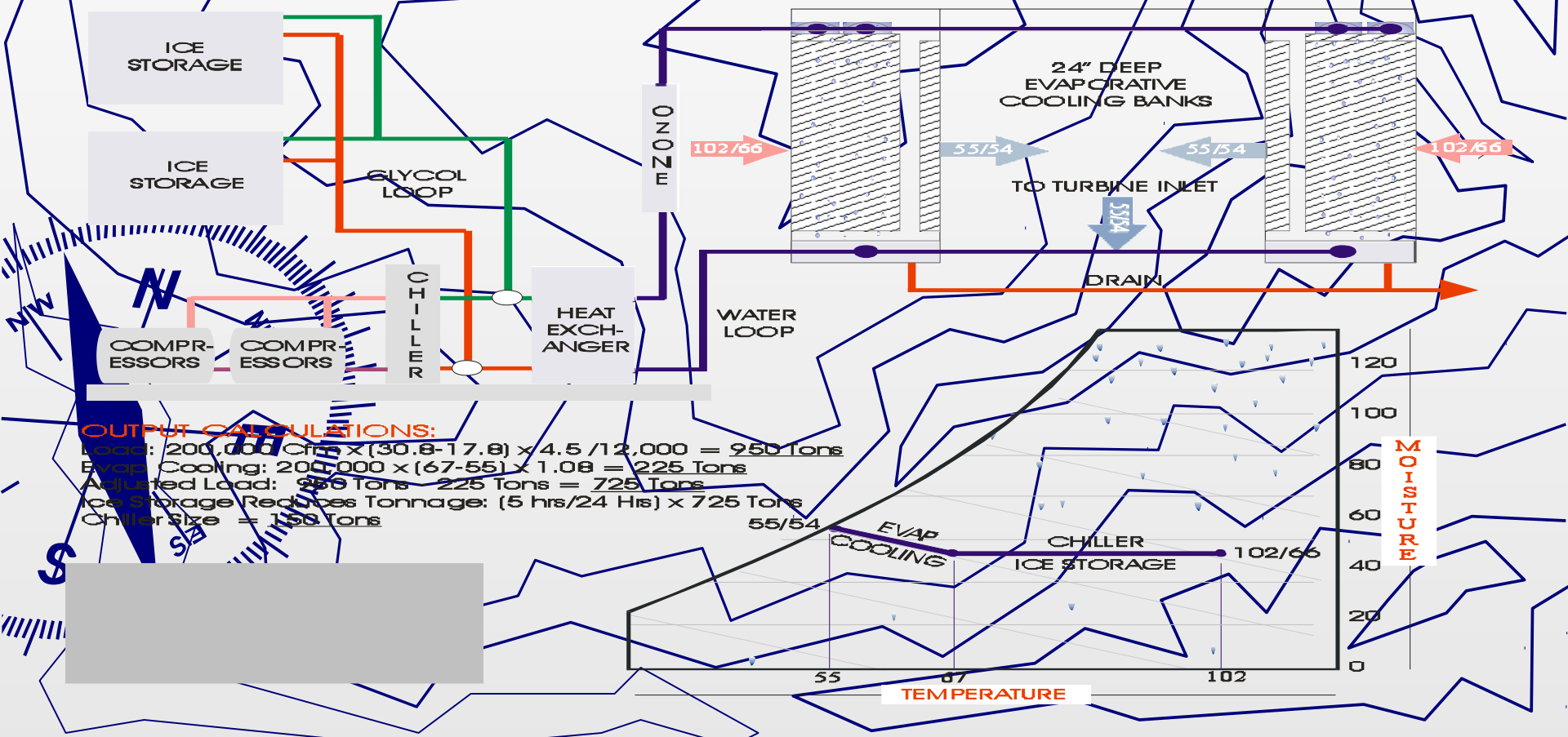
TURBINE POWER BOOSTER PACKAGE

EVAPORATIVE COOLING - ICE STORAGE - CHILLER

GENERAL DESCRIPTION: The most efficient means of boosting turbine peak power and efficiency is a hybrid system that synergetically combines the best of several technologies

ICE STORAGE: Peak power demand lasts about 5 hours a day. With ice storage, the chillers can spend 19 hours making ice, thus reducing the chiller plant to about one sixth the normal size.

EVAPORATIVE COOLING MEDIA: 24" deep evaporative media banks have replaced chilled water coils to increase cooling output and reduce the required ton-hours of the chiller /ice storage system. On a Las Vegas design day, the evaporative cooling effect does 30% of the work. During less severe weather, it can handle 100% of the load.



OUTPUT CALCULATIONS:

Load: 200,000 Cfm x (30.8-17.8) x 4.5 /12,000 = 950 Tons

Evap. Cooling: 200,000 x (67-55) x 1.08 = 225 Tons

Adjusted Load: 950 Tons - 225 Tons = 725 Tons

Ice Storage Reduces Tonnage: (5 hrs/24 Hrs) x 725 Tons

Chiller Size = 150 Tons

High Performance Hybrid HVAC: Institutional/Office Applications

- Wausau West High School Wausau, WI
- Problems they were facing:
  - Expensive retrofit of existing chiller and boiler plants
  - Severe indoor air quality problems
  - Non-compliance with Standard 62
  - Rising energy costs

High Performance Hybrid HVAC: Components

- The **Regenerative Double Duct™** is a hybrid, multi-component/function design that is proving to be one of the most energy efficient HVAC systems available. Its major components are:
  - **Indirect Evaporative Cooler (IDEC)**
    - First stage cooling
    - First stage heating
    - Limited capacity to act as a cooling tower
  - **Direct Evaporative Cooler (DEC)**
    - Direct evaporative cooling (when conditions permit)
    - Air filtration/scrubbing
    - Humidification

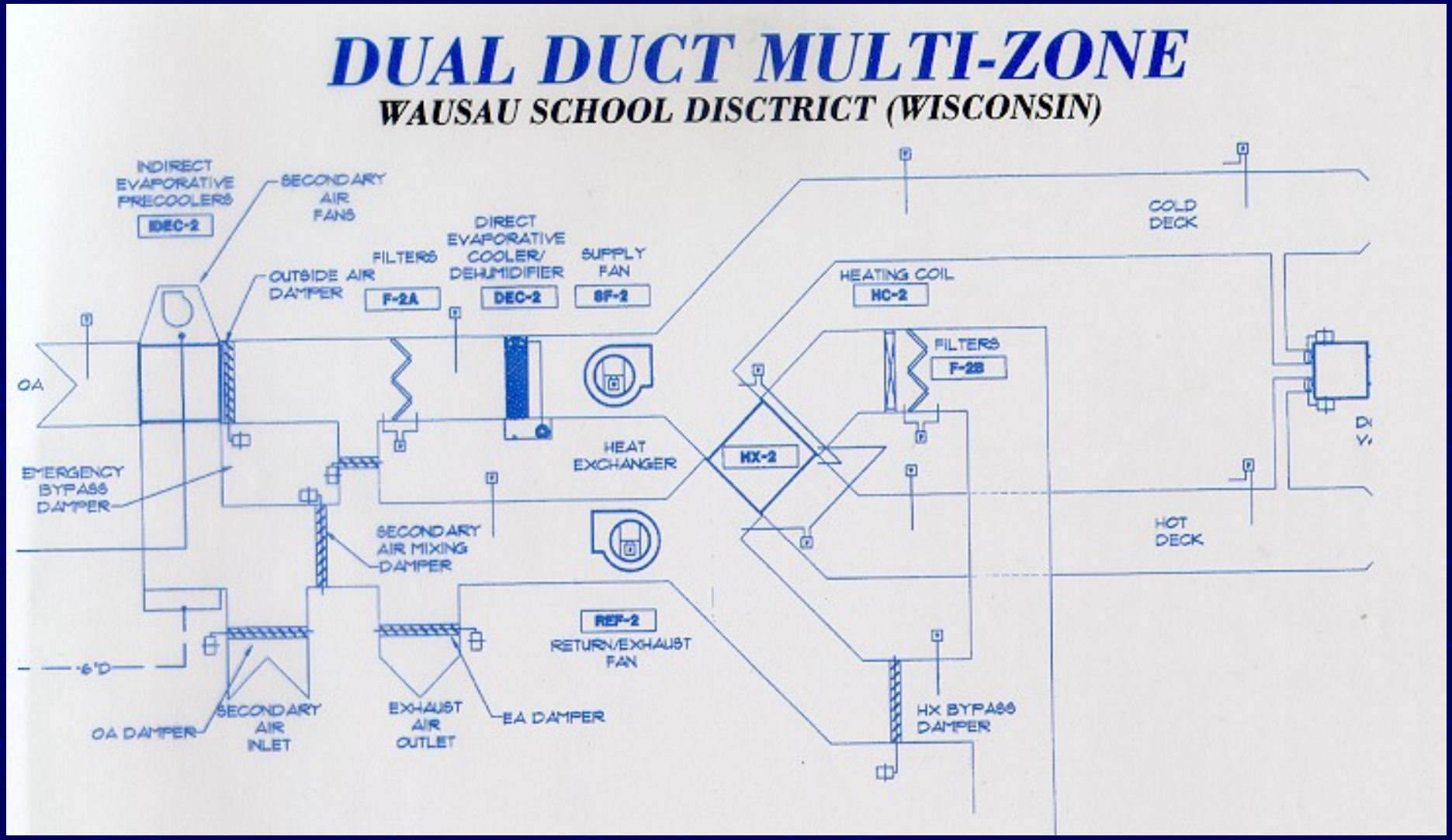
High Performance Hybrid HVAC: Components

- **Secondary Plate-And-Frame Heat Exchanger (HX)**
  - Provides heating for the hot deck
  - Sub-cools building exhaust
- **Thermal Energy Storage**
  - Makes ice during less expensive time of day
  - Flattens out the demand curve
- **Chilled Water**
  - Supplemental cooling
  - Supplemental dehumidification
- **Boilers**
  - Perimeter heating
  - Supplemental heating

High Performance Hybrid HVAC: Components

- **Heating Coil**
  - Pre-heat (on building exhaust)
  - Supplemental heat
  - Defrost (for IDEC)
- **Filtration**
  - Supply
  - Exhaust
- **Water Treatment**
  - Ozonation
  - Mechanical (non-chemical)
  - Filtration
- **Building Automation System (Controls)**

High Performance Hybrid HVAC: Schematic

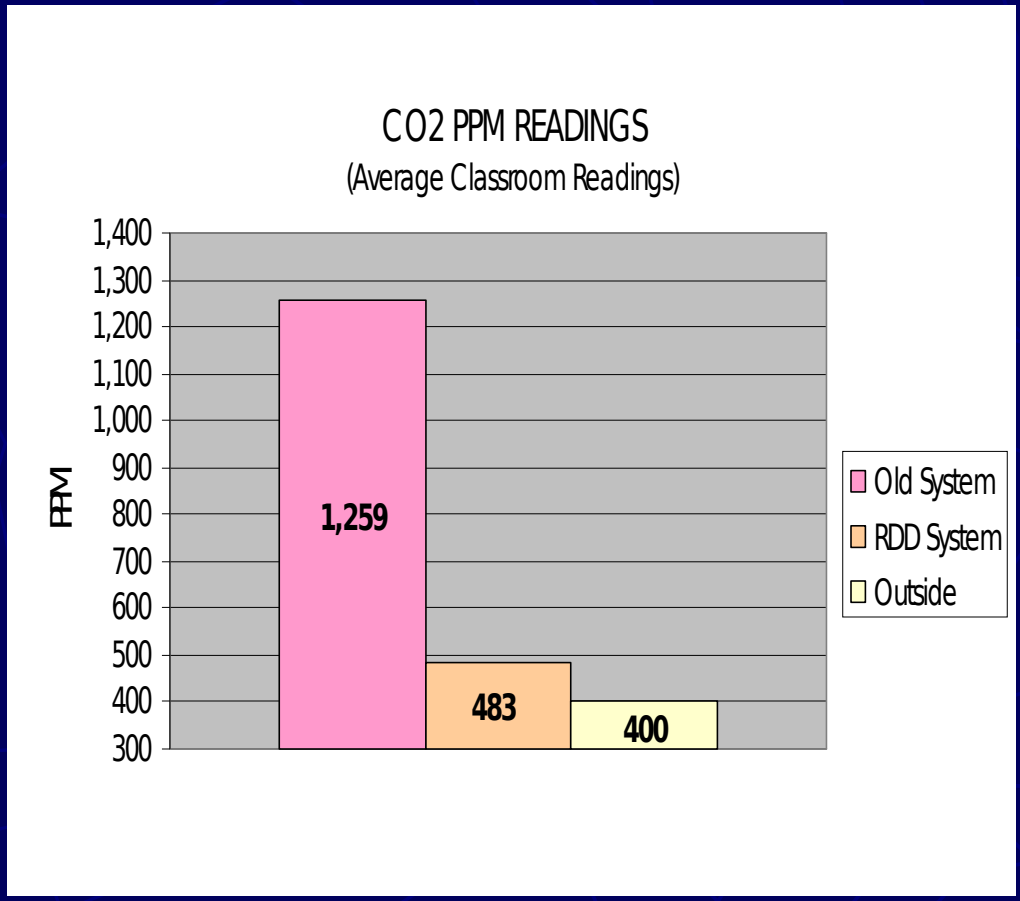


High Performance Hybrid HVAC: Results

- Wausau West High School
- Area: 275,000 S/F
- System Type: **100% Outside Air (Replaced minimum OSA)**
- Primary Heating Plant Reduction: 60%
- Primary Cooling Plant Reduction: 92%
- Gross Energy Use Reductions:
  - Natural Gas: 38%
  - Electricity (kWh): 27.8%
  - Electrical Demand: 25%
- Gross Energy Cost Reductions: 29.3%
- CO_2 Reduction: 262%

High Performance Hybrid HVAC: IAQ Improvements

ASHRAE Standard 62-1 uses an indoor to outdoor differential concentration not greater than 700 ppm of CO_2 as an indicator of acceptable indoor air quality.



CO_2 Reductions of 262% in the Classrooms

High Performance Hybrid HVAC: New Construction

- Clintonville High School, Clintonville WI
- Size: 212,000 S/F
- System: RDD - 100% OSA - 98,700 CFM
- Mechanical Cost: $12.67 Per S/F
- Hours of Operation: 5:00 a.m. to 11:00 p.m. (the school is also utilized as a community center) Sunday-Saturday
- First year actual energy usage (entire building):
  - Electricity: 2,042,666 kWh
  - Gas: 109,801 therms
  - Gross energy costs: $190,127.00
  - **Cost per S/F: $0.8968**
  - **State average for similarly sized schools: $1.32/SF**

High Performance Hybrid HVAC: New Construction

- **Stephen Mack Middle School, Rockton IL**
- Size: 99,771 S/F
- System: RDD - 100% OSA - 45,600 CFM
- Mechanical Cost: **$10.22/SF**
- Hours of Operation: 7:00 a.m. to 6:00 p.m.
- First Year Actual Energy Usage (Entire Building):
  - Electricity: 614,600 kWh
  - Gas: 36,663 therms
  - Gross Energy Costs: $63,395.85
  - BTU Per S/F: **57,766**
  - Cost Per S/F: **$0.6354**

High Performance HVAC Comparison To Standard HVAC

- Two schools built at the same time 40 miles apart
  - School A (previous slide): high performance HVAC (100% OSA)
  - School B: standard mechanical recirculation VAV reheat (Standard 62.1 compliant)
- The result:
  - School A has a lower first cost!
  - School A has a much lower annual operating cost!!
  - School A has a much, much lower life cycle cost!!!

LONG TERM COST BENEFITS OF HIGH PERFORMANCE HVAC

School A vs. School B

Actual Energy Performance Comparison

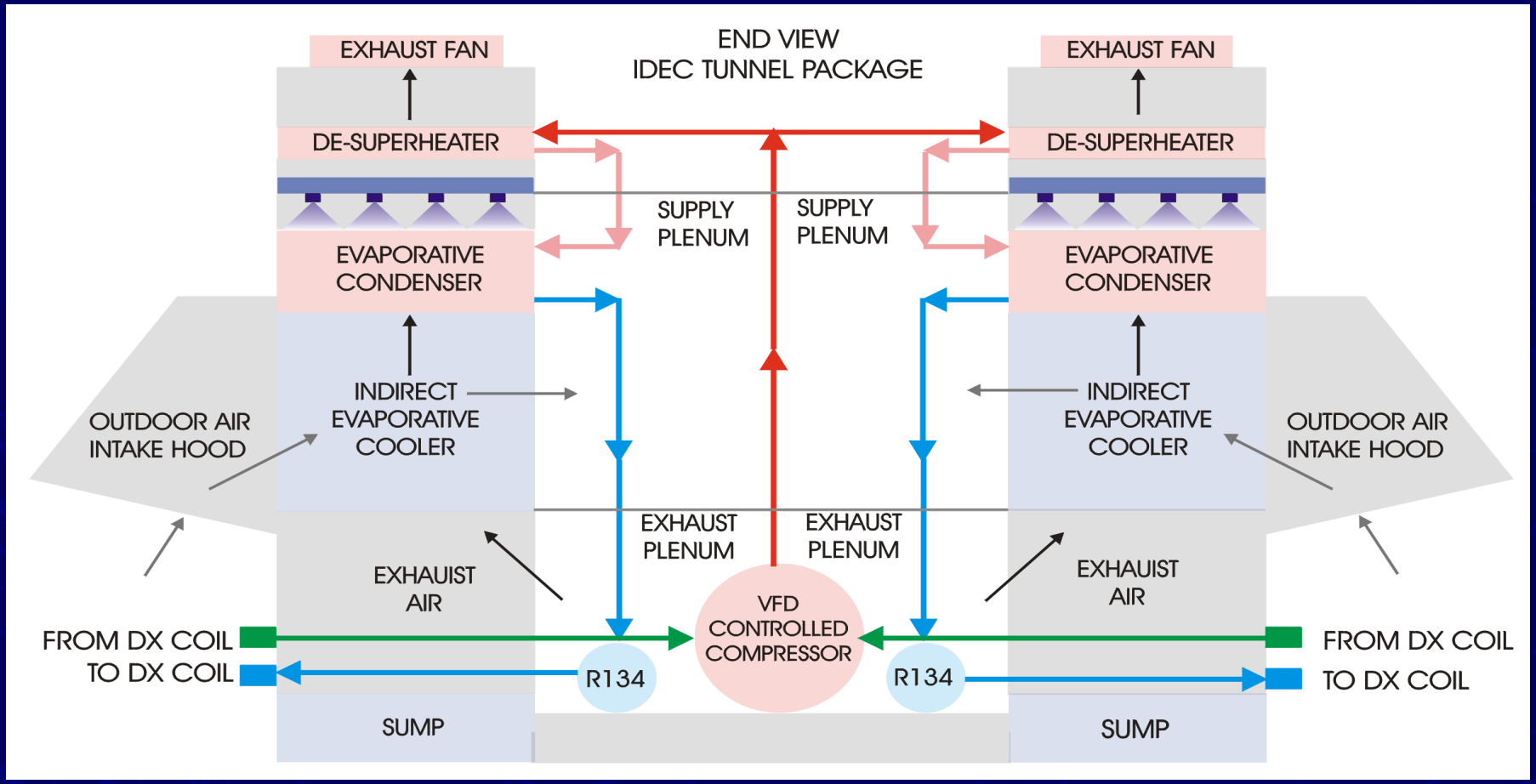
Fuel Inflation Rate	3%	System Cost	Energy Use Btu/SF/YR	Energy Cost $/SF/YR	Adjusted Annual Costs
School A System		**$ 1,019,660**	57766	$ 0.6354	$ 63,394
School B System		**$ 1,845,764**	158608	$ 1.8484	$ 184,417

Year	School A	School B	Annual Savings	Net Savings
1	$ 63,394	$ 184,417	$ 121,022	$ 947,126
2	$ 64,979	$ 189,027	$ 124,048	$ 1,071,174
3	$ 66,604	$ 193,753	$ 127,149	$ 1,198,323
4	$ 68,269	$ 198,597	$ 130,328	$ 1,328,651
5	$ 69,976	$ 203,562	$ 133,586	$ 1,462,237
6	$ 71,725	$ 208,651	$ 136,926	$ 1,599,162
7	$ 73,518	$ 213,867	$ 140,349	$ 1,739,511
8	$ 75,356	$ 219,214	$ 143,857	$ 1,883,368
9	$ 77,240	$ 224,694	$ 147,454	$ 2,030,822
10	$ 79,171	$ 230,311	$ 151,140	$ 2,181,962
11	$ 81,150	$ 236,069	$ 154,919	$ 2,336,881
12	$ 83,179	$ 241,971	$ 158,792	$ 2,495,672
13	$ 85,259	$ 248,020	$ 162,761	$ 2,658,434
14	$ 87,390	$ 254,220	$ 166,830	$ 2,825,264
15	$ 89,575	$ 260,576	$ 171,001	$ 2,996,266
16	$ 91,814	$ 267,090	$ 175,276	$ 3,171,542
17	$ 94,109	$ 273,768	$ 179,658	$ 3,351,200
18	$ 96,462	$ 280,612	$ 184,150	$ 3,535,350
19	$ 98,874	$ 287,627	$ 188,753	$ 3,724,103
20	$ 101,346	$ 294,818	$ 193,472	**$ 3,917,575**

High Performance Hybrid HVAC: Unitary Systems

- Roof-top units can be designed with many of the same components and efficiencies of the built-up systems
  - Indirect evaporative precooling/preheating
  - Direct evaporative cooling/humidification
  - Evaporative condenser
  - Downsized centrifugal compressor and cooling coil
  - Downsized hot water coil or furnace
  - Dual duct and single duct configurations

High Performance Hybrid HVAC: Unitary Systems



Refrigeration System EER's in the **20's**

Total System EER's in the **50's**

Evaporative Cooling Does It Waste Water?

- So, everything sounds great, but…aren't we supposed to be conserving water for better sustainability?
- Absolutely…and evaporative cooling does!
- Evaporative based hybrid systems, when taking into account power plant point of production water usage:
  - Use about the same amount of water as an air cooled system
  - Use less water than a water cooled system
  - Use a lot less water than a ground source heat pump system

High Performance Hybrid HVAC Conclusions

- Classical HVAC system strategies and equipment are not meeting your needs:
  - They are constructed around energy intensive processes
  - Recirculation compromises IAQ and energy efficiency
- In seeking a solution, avoid “one solution fits all” thinking. This leads to the “cookie cutter” approach to design so prevalent in the HVAC industry.
- Truly green HVAC systems are attainable with simple technologies that are readily available.

High Performance Hybrid HVAC Conclusions

- Benefits of these green systems:
  - Competitive construction/first costs
  - Improved indoor air quality
  - Reduced energy consumption
  - Smaller heating/cooling plants
  - Easy to maintain
- In short, a “win-win-win” solution for a tough problem!